

Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), 5 – 6 September 2006, Kuala Lumpur, Malaysia

MICROSTRUCTURAL BEHAVIOR OF AERATED CONCRETE CONTAINING HIGH VOLUME OF GGBFS

N. Arreshvhina¹, Z. Fadhadli¹, H. Mohd Warid¹, A.H. Zuhairy², Roswadi²

¹Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

²Construction Industry Development Board of Malaysia (CIDB), 53000, Kuala Lumpur, Malaysia

¹E-mail: nsarreshvhina@hotmail.com

ABSTRACT: Aerated concrete is a lightweight engineering material, which is produced by introducing air bubbles into normal concrete. Their properties depend on their internal structures, and also vary tremendously with age, curing, and also not forgetting the ratio of constituent materials. This paper reports the compressive strength and microstructural changes in two types of aerated concrete mix, exposed to various curing conditions. The two types of mix is one with 100 percent OPC (MCTR), while the other one with 65 percent slag replacement (M65). The specimens were cured in air, seawater, and natural weather for the period of six months. The compressive strength was tested at 14, 28, 90, and 180 days, while micrograph of the internal structure were taken at the age of 14, and 180 days. The micrograph was taken using scanning electron microscope (SEM). The results show that mix MCTR exhibits much less strength compared with M65, for all curing conditions. However in both mixes, the specimen exposed to seawater shows the lowest strength. Scanning electron micrograph of both mixes also presents various structure formations in relation with curing condition, age, and also the effect of slag. The outcome of this study may establish a better understanding on the relationship between microstructure and compressive strength of aerated concrete containing high volume of GGBFS.

Keywords – GGBFS; SEM; aerated concrete; lightweight concrete; microstructure

1. INTRODUCTION

Generally it has been traditionally practiced to evaluate the concrete through its mechanical, physical, and functional properties. However, often we disregard, that these properties are the result of the ‘internal architecture’ that makes up the concrete. Microstructure-property relationship is at the heart of modern material science. Concrete is highly heterogeneous and has very complex microstructure. Therefore, it is very difficult to constitute a realistic model of its microstructure in order to understand the behavior of the material. The microstructure of concrete also changes with age, cement content, the water: cement ratio, curing, chemical admixtures, and incorporation of pozzolan material (slag, fly ash, etc.) (Sidney 2004). Furthermore many concrete in service are subject to deterioration by various chemical and physical processes, all of which modify their internal structures as well as their end-use properties. Scanning electron microscopy (SEM) has been a primary tool in the investigation of the complex internal structure of concretes and hydrated cement pastes for many years. While the ‘internal architecture’ of concrete can be studied by various techniques, no other technique can provide the depth and breadth of information available with SEM (Sidney 2004).

In aerated concrete, pore system can be divided into three regions. One of them consists of air pores with a radius of 50 to 500 μm introduced by hydrogen gas during the manufacturing process. Another region is featured by micro-capillaries of 50 nm or less, which is the gap of the hydration products developed in the wall between the air pores. Besides these two regions, there are very few pores with size of 50 nm to 50 μm , which is referred as macro-capillaries (Alexanderson 1979; Prim et al. 1983; Tada et al. 1983).

According to Narayanan et al. (2000), even though the air void system remains largely identical, there still exists some difference in the structure of autoclaved aerated concrete (AAC) and non-autoclaved aerated concrete (NAAC). This is caused by mainly due to the variation in the hydration products. On autoclaving, a part of fine siliceous material reacts chemically with calcareous material like lime and lime liberated by cement hydration, forming a microcrystalline structure with much lower specific surface, which would result in higher strength. On the other hand, non-autoclaved aerated concrete (NAAC) has a larger volume of fine pores due the presence of excessive pore water (Tada et al. 1983). However, it has been observed that macro-pore size distribution does not have much influence on compressive strength (Alexanderson 1979).

In general microstructural changes occurs due to the variance in exposure conditions, composition variations, and age. These changes will significantly affects the properties of aerated concrete. According to Narayanan, et al. (2000), non-autoclaved aerated concrete (NAAC) undergoes changes in structure with time whereas autoclaved aerated concrete are practically stable. There are also clear indications of the existence of a transition zone at the void-paste interface. However, the transition zone in aerated concrete is less porous compared to normal concrete. This is due the constriction of the matrix by the voids and the unlimited space available for hydration as well as for bleed water to move about.

Therefore, at least a nodding acquaintance with the internal architecture of aerated concrete in relation with the compressive strength would be beneficial to all who deal with concrete properties and with concrete behavior in service. This is particularly true for the expanding community of those engaged in developing mathematical models of concrete and of concrete durability.

2. EXPERIMENTAL PROGRAM

The experimental work comprises of compressive strength test and SEM studies on two types aerated concrete mixes, which was air cured and also exposed to natural weather and seawater. Cement base and slag replaced matrix were prepared to assist the comparative studies on the effect of slag on aerated concrete. Ordinary Portland cement of “Holcim” brand was used throughout the experimental investigation. The OPC used complies with the requirements in ASTM C150 (1992). Ground granulated blast furnace slag used was in accordance with ASTM C989 (1989). The slag activity index was 100. The sand used was sieved to the fineness of passing 600 μm . Aluminum powder was used as expanding agent to produce air bubbles in the mix, and superplasticizer was used to enhance the early strength of the material. Cubes with the size of 70.6 x 70.6 x 70.6 mm was prepared to study the compressive strength. Compressive strength was tested at the age of 14 days, 28 days, 90 days, and 180 days. For the microstructural investigation, broken specimens with the size of about 10 mm were used. The specimens were mounted on a metal stubs, sputter-coated with gold before subjecting to the scanning electron microscopic. The specimen was coated, in order to transform it from non-conductive material into conductive material. The images of microstructure were taken at the age of 14 days, and 180 days for all three types of curing conditions.

3. RESULTS AND DISCUSSION

Compressive strength results of both types aerated concrete mix are presented in Table 1. Generally, the result shows that ground granulated blast furnace slag (GGBFS) based aerated concrete presents an excellent behavior in both short-term and long-term compressive strength, compared with control mix. The overall SEM observation of aerated concrete (Figs. 1 to 12) indicates that the microstructure changes greatly with the inclusion of GGBFS. The majority of hydration products from both types of mixes are mostly cotton-shaped C-S-H gel,

certain amount of needle like ettringite, and also hexagonal shaped calcium hydroxide. Another general criteria that can be observed from the microstructure of slag cement based aerated concrete is that it has much larger specific surface compared to Portland cement based aerated concrete. This could be due the fact that, when GGBFS reacts with the hydrated lime (CH) of Portland cement, a secondary calcium silicate compound is formed, and also creates a lot of homogeneous hydration product like ettringite and CH, which have large specific surface (Gengying Li et al. 2003). The salient observations pertaining to the structure and its influence on compressive strength in relation with exposure conditions are discussed in the following sections.

3.1 Air Cured aerated concrete

Figs 1 and 2 show the microstructure of air-cured aerated concrete with and without slag, respectively, at the age of 14 days. At early stage both mixes seem to be like not has completed the hydration process. This is because, from Figs 1 and 2, it can be observed that, there still appear some spaces. However, the hydration process of slag cement based aerated concrete seem to be faster than pure cement based aerated concrete. This is justified by the compressive strength achieved by both mixes. The slag cement based aerated concrete shows much higher strength compared to the other mix (Table 1). Even tough, some researchers have reported that, slag cement based concrete gives lower early strength (Gengying Li et al. 2003), and also retards the setting time (Hogan et al. 1981). However this is not acceptable particularly for this study. The reason for this could be due the usage of superplasticizer, which has the potential to increase the early strength.

Micrograph of air cured aerated concrete at 180 days is shown in Figs 3 and 4, respectively, for 100 percent cement based aerated concrete and slag cement based aerated concrete. Large hexagonal shaped crystal and needle shaped ettringite can be observed from both mixes as in Figs. 3 and 4. However, Fig. 3 shows that there was no continuity in the structure formation, while, on the hand, the structure of slag cement based aerated concrete is also seem to be more complete, which resulted in much better strength compared to the other type of mix. Micrograph of 100 cement based aerated concrete also indicates some empty space, which is the resulted from un-hydrated area. This could be the reason for cement based aerated concrete to give lower strength compared to the slag cement based aerated concrete. At six months the strength of aerated concrete was 13.68 MPa and 16.89 MPa, respectively for mix type MCTR and M65. This shows that the strength of slag cement based aerated concrete increases by 24 percent compared to control mix, even with high slag content.

3.2 Aerated concrete submerged in seawater

Exposing concrete to seawater has been found to influence the properties of concrete in many ways, particularly its strength. Therefore, it is important to study the effect of seawater on the aerated concrete, particularly in this country, which surrounded by sea. The result could explain the effect of slag on the compressive strength and microstructure of aerated concrete submerged in seawater.

Figs. 5 and 6 pictures the microstructure of aerated concrete in seawater at fourteen days, respectively for mix MCTR and M65. As usual the strength increases with the inclusion of slag. The strength at fourteen days was 7.66 MPa and 8.65 MPa for mix type MCTR and M65. From the micrograph of MCTR at fourteen days, some small cotton shaped hydrated products can be observed. On the other hand, the micrograph of M65 shows more wide solid surface, and some small amount of hexagonal crystals ($\text{Ca}(\text{OH})_2$), which will be transformed into additional C-S-H. This creates a basis for improvement in strength, which could be observed from the result in Table 1. The strength of aerated concrete continue to increase up

to three months, with M65 recording higher strength. At three months the compressive strength was 8.94 MPa and 12.22 MPa, respectively for mix MCTR and M65.

However, the strength at six months shows some reduction, where by the strength of MCTR dropped by almost fifty percent and M65 dropped by almost 25 percent compared to three months strength. The micrograph of M65 at 180 days does not show any drastic changes compared to Fig. 6. However, there was no hexagonal crystals (calcium hydroxide) were observed at 180 days. Therefore, this indicates that there will be no more hydration process. The micrograph of control mix shows some pore spaces and also some needle like ettringites. However, most part is still covered by cotton shaped hydration product as in Fig. 5. The reason for the drop in strength could be due to the sulfate attack from the seawater, which has started to react with aerated concrete only after three months. The seawater may have entered the concrete due to the highly porous structure of aerated concrete.

3.3 Aerated concrete exposed to natural weather

A country, geographically located in area with tropical weather, receives rain and sun for the whole year. Therefore it is important to understand the strength development of aerated concrete in relation with Malaysian weather. The average humidity was 25 percent on hot and dry days, and 90 percent on rainy days, while the temperature was 25°C on rainy days and 38°C on hot days. Table 1 shows the results of compressive strength of aerated concrete exposed to natural weather.

The micrographs of aerated concrete exposed to natural weather at fourteen days are imaged in Figs 9 and 10, respectively for mix MCTR and M65. Fig. 9 shows some sharp needle-shaped. However, it is not the ettringite, but only ongoing hydration process. The microstructure of M65 at fourteen days showing some large hexagonal crystals and cotton-shaped C-S-H product. The compressive strength at fourteen and twenty-eight days doesn't have any significant differences. The strength at fourteen days was 10.19 MPa and 10.96 MPa, respectively for mix MCTR and M65, while the strength at twenty-eight days was 11.14 MPa and 11.85 MPa. The difference in compressive strength is only about six to seven percent. However the margin increased drastically at three months and beyond. The strength at three months was 11.85 MPa and 14.12 MPa, with difference of about twenty percent.

A lot of thin needles of ettringites were observed from the Fig. 11, while Fig. 12 show small amount of ettringite with most of the space is covered with cotton-shaped C-S-H product. The microstructure of MCTR at 180 days also shows some un-uniformed hexagonal crystal, with broken edges on it. In term of strength development, MCTR doesn't show big improvement in comparison with fourteen days strength. The strength of control mix at six months was 12.63 MPa, with only 24 percent increase. The strength of slag cement based aerated concrete (M65) increased more than 50 percent, compared with fourteen days strength. The compressive strength of M65 at six months was 16.87 MPa.

4. CONCLUSIONS

The significant conclusions as observed from the experimental investigations with reference to the composition and treatment of the samples studied are given below.

1. The microstructural alterations, either due to compositional variation (100 percent cement or slag cement based) or curing conditions (air, seawater or natural weather) significantly affects the properties of aerated concrete.
2. Aerated concrete with sand and slag exhibits considerable difference in structure because of the relative variations in degree of hydration with time.
3. The compressive strength of air-cured and natural weather exposed sample is much higher compared to sample submerged in seawater.

4. Presence of slag in aerated concrete increases the compressive strength by eight to 63 percent compared to the aerated concrete without slag. However, the percentage differs according to exposure conditions.
5. High content of slag improves the strength development of aerated concrete, as well as forms better microstructure.

5. ACKNOWLEDGEMENT

The author is grateful to the Technical staffs of the structure and material laboratory of Faculty of Civil Engineering, and material science laboratory of Faculty of Mechanical Engineering of Universiti Teknologi Malaysia for the testing. Financial support from the Construction Industry Development Board of Malaysia (CIDB) is also greatly appreciated.

6. REFERENCES

- Alexanderson, J., 1979. Relations between structure and mechanical properties of autoclaved aerated concrete. *Cement & Concrete Research*. Vol. 9: 507.
- American Society for Testing and Materials. *Standard Specification for Portland Cement*. Philadelphia, ASTM C150. 1992
- American Society for Testing and Materials. *Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars*. Philadelphia, ASTM C989. 1989
- Gengying Li and Xiaohua Zhao., 2003. Properties of concrete incorporating fly ash And ground granulated blast-furnace slag. *Cement & Concrete Composites*. Vol. 25: 293 – 299.
- Hogan, FJ and Muesel JW. 1981. Evaluation for durability and strength development of a ground granulated blast furnace slag. *Cement Concrete Aggregates*. Vol. 3: 40-52.
- Malhotra, V.M. and Ramezaniapour, A.A., 1995. Effect of curing on the compressive strength, resistance to chloride-ion penetration and porosity of concretes incorporating slag, fly ash or silica fume. *Cement & Concrete Composites*. Vol. 17: 125 – 133.
- Narayanan, N. and Ramamurthy, K., 2000, Structure and properties of aerated concrete:a review. *Cement & Concrete Composites*. Vol. 22 : 321 – 329.
- Prim, P. and Wittmann, F.H., 1983. Structure and Water Absorption of Aerated Concrete. *Proceedings of the RILEM International Symposium on Autoclaved Aerated Concrete*. March, 1982. Amsterdam, The Netherlands: Elsevier. Vol. 6: 55 – 69.
- Sidney, D. 2004. Special issue on scanning electron microscopy pf cements and concretes. *Cement & Concrete Composite*. Vol. 26: 917 – 918.
- Tada S. and Nakano, S., 1983. Microstructural approach to properties of moist cellular concrete. *Proceedings of the RILEM International Symposium on Autoclaved Aerated Concrete*. March, 1982. Amsterdam, The Netherlands: Elsevier. Vol. 6: 71 – 88.

7. BIBLIOGRAPHY

- Escalante-Garcia, J.I., and Sharp, J.H., 2004, The chemical composition and Microstructure of hydration products in blended cements. *Cement & Concrete Composites*. Vol. 26: 967 – 976.
- Gao, J.M., Qian, C.X., Liu, H.F., Wang, L., and Li, L. 2004. ITZ microstructure of concrete containing GGBS. *Cement & Concrete Research*. Article in Press.
- Hulya Kus and Thomas Carlsson., 2003. Microstructural investigations on naturally and artificially weathered autoclaved aerated concrete. *Cement & Concrete Research*. Vol.33: 423 – 432.
- Xi-Shu W., Bi-Sheng W., and Qing-Yuan W. 2004. Online SEM investigation of microcrack characteristics of concretes at various temperatures. *Cement & Concrete Research*. Article in Press.

Table 1: Compressive strength of aerated concrete

Age	Compressive Strength (MPa)					
	MCTR			M65		
	Air	Seawater	Nat. weather	Air	Seawater	Nat. weather
14 days	8.92	7.66	10.19	10.52	8.65	10.96
28 days	11.93	8.27	11.14	12.84	10.39	11.85
90 days	12.22	8.94	11.85	15.88	12.22	14.12
180 days	13.68	6.02	12.63	16.89	9.82	16.87

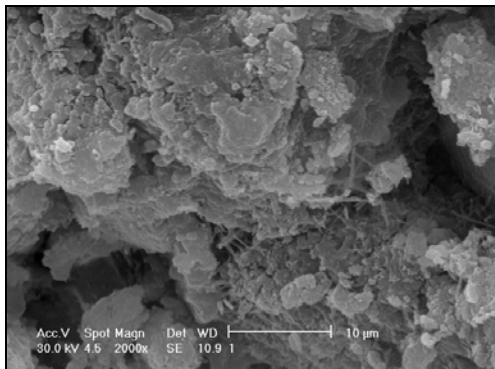


Fig. 1: Air curing for 14 days (MCTR)

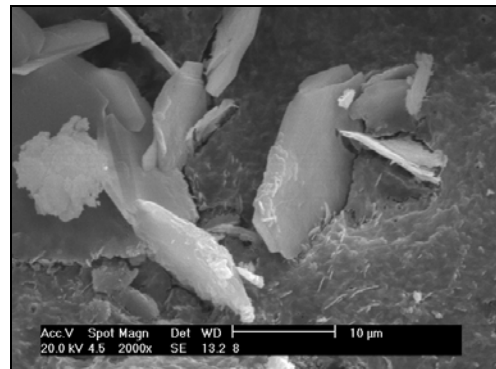


Fig. 2: Air curing for 14 days (M65)

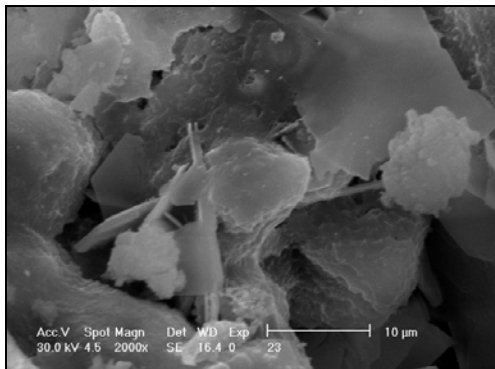


Fig. 3: Air curing for 180 days (MCTR)

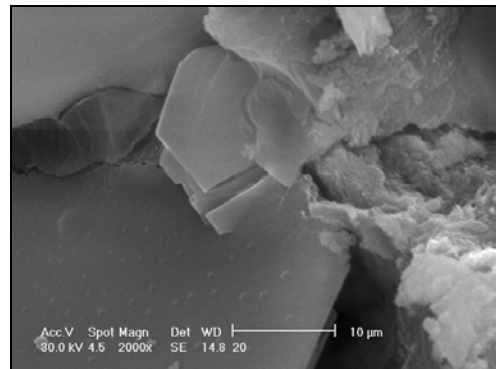


Fig. 4: Air curing for 180 days (M65)

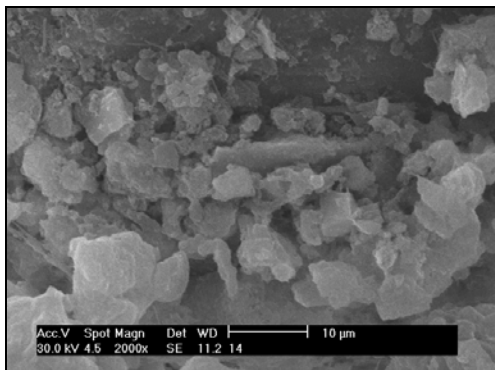


Fig. 5: Seawater for 14 days (MCTR)

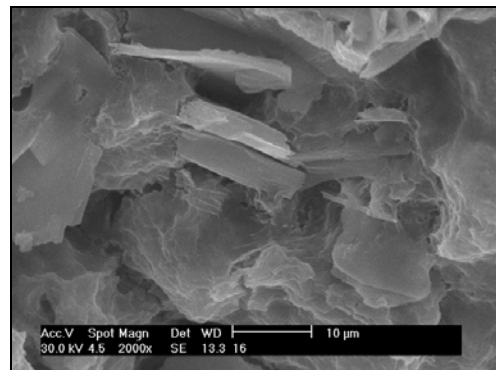


Fig. 6: Seawater for 14 days (M65)

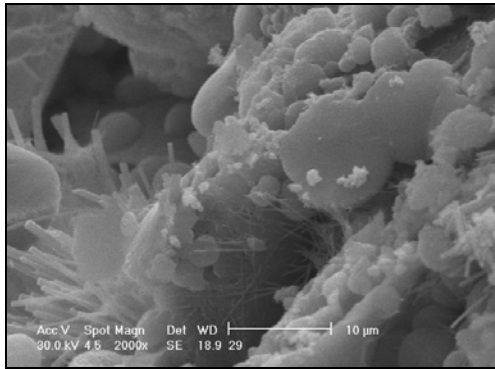


Fig. 7: Seawater for 180 days (MCTR)

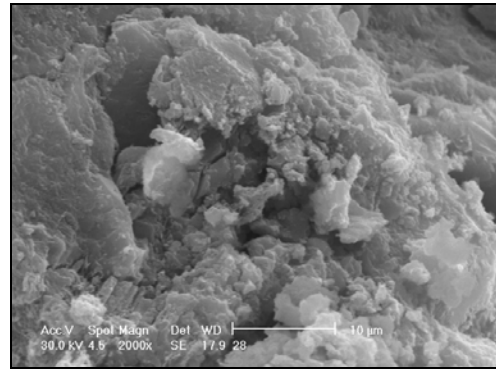


Fig. 8: Seawater for 180 days (M65)

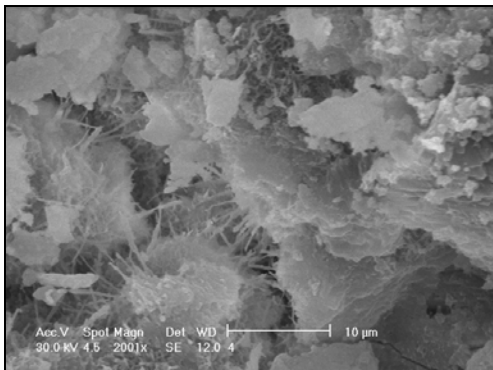


Fig.9: Nat. weather for 14 days (MCTR)

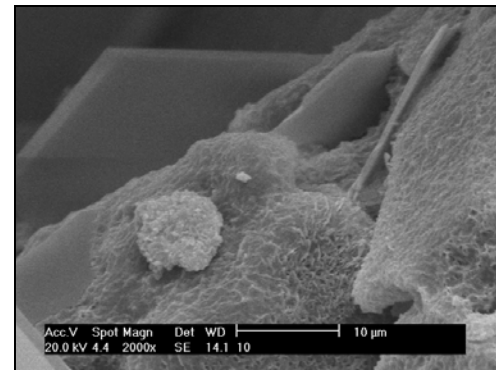


Fig.10: Nat. weather for 14 days (M65)

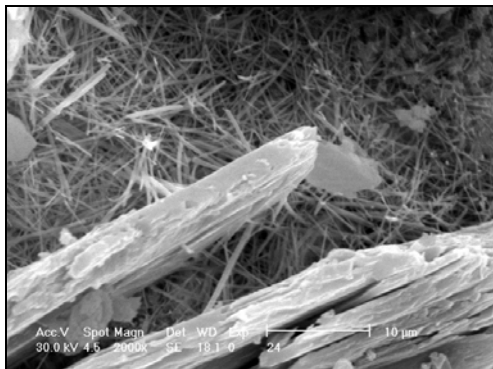


Fig.11: Nat. weather for 180 days (MCTR)

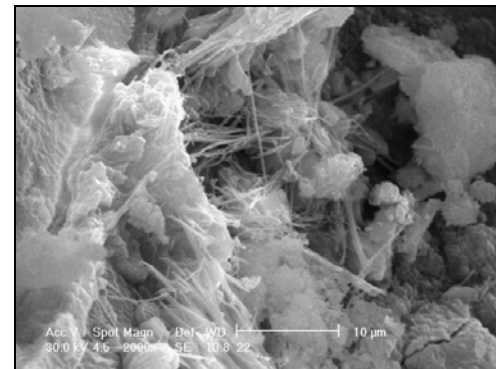


Fig.12: Nat. weather for 180 days (M65)